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DYNAMIC WIND LOADING OF H-SHAPED TALL BUILDINGS

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ABSTRACT

Dynamic wind loads on a number of H-shaped tall buildings are measured in the wind tunnel with a high-frequency force balance for all wind incidences. The aim is to investigate the size effect of the recessed cavities on the dynamic wind loading behavior of the building. Combinations of three widths and three depths of a cavity are tested. It is found that at most wind incidences, the presence of cavities on the building faces leads to little modifications to the magnitudes and behavior of mean and fluctuating overturning moment coefficients. However, reduced magnitudes of across-wind moment fluctuations are found at normal incidence and different behavior of across-wind excitation is revealed by the across-wind moment spectra. Wind torsion is noticeably modified by the presence of the recessed cavities.

KEYWORDS: DYNAMIC WIND LOADS, TALL BUILDINGS, SHAPE FACTOR

Introduction

Tall and slender buildings are strongly wind sensitive. Different mechanisms are responsible for wind-induced responses and dynamic loads in the along-wind, across-wind and torsional directions. Databases for aerodynamic loads such as “NatHaz” are useful in providing some first-stage design data for tall buildings of various geometries and in different exposures (Zhou et al. 2003). The data are based on wind tunnel tests in which mean, RMS (root-mean-square) moment coefficients and spectra of along-wind, across-wind and torsional moments on rigid models of tall buildings are measured with the high-frequency force balance (HFFB).

In a densely populated city, residential tall buildings are common and the design of an irregular cross-sectional shape with apartments arranged as wing sections extending from a central core is usually adopted. Between adjacent building wings are deeply recessed re-entrant bays (recessed cavity) or “light-wells” towards which kitchen and bathroom windows are opened. This design is aimed at maximizing the number of apartments on a floor while providing the necessary views and ventilation services to all apartments.

Architectural details are known to modify wind loading of a tall building (e.g., Kwok 1988). There have been few studies on wind loads of building with recessed re-entrants and the resulting irregular building cross-sections. Some general statements have been made by the Building Research Establishment, UK that for narrow recessed bays, flow tends to skip past the bays and leave almost stagnant flow inside so that pressure inside the bay is uniform and equals the average pressure on the opening face of the bay (Cook 1985). In this paper, building models with recessed cavities of different sizes are tested in the wind tunnel to investigate the effect of the recessed cavity on the dynamic wind loads of a tall building.

Experimental Setup

Tests were carried out in the boundary layer wind tunnel of the Department of Civil Engineering at the University of Hong Kong. The working section of the tunnel was 12.0 m long, 3.0 m wide and 1.8 m tall. Simulation of natural wind was achieved using triangular spires and floor roughness elements (Lam et al. 2008). The open land terrain type was simulated and the mean wind speed profile was measured to follow the power law with the power exponent at about 0.15.

The tall buildings being tested all had the cross-section of square envelopes. They were 0.6 m (H) in height and 0.1 m (B) in breadth (H/B = 6). The target geometric scale was 1:300 so that the tall building would have a full-scale size of 180 m by 30 m by 30 m. In addition to the control square building, tests were made on nine other building models in which two recessed cavities of varying sizes were put on opposite walls of the building. This resulted in an "H"-shaped planform of each building model (Figure 1). The horizontal dimensions of the recessed cavities vary in a systematic manner covering three different widths, W/B = {0.25, 0.5, 0.75} and three different depths, D/B = {0.125, 0.25, 0.375}.

Mean and fluctuating wind loads on each building model were measured with a HFFB at a number of wind incidence angles between 0 and 90°. Pressure models were also built for some configurations in which surface pressure taps were installed at five levels of each model. Near-simultaneous pressure measurements were made using high-speed pressure scanning.

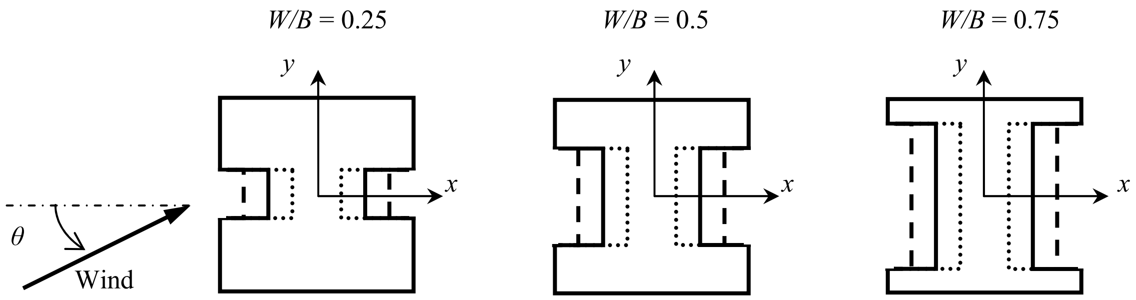

Figure 1: Nine H-shaped building sections tested. For each cavity width (W), there are 3 depths: D/B = {0.125, 0.25, 0.375}.

Results and Discussion

For a square tall building, the variations of mean wind loads with wind angles have been well documented (Lam et al. 2008). In this study, it is found that the presence of recessed cavities on two sides of the building do not lead to any significant modifications of mean wind load distributions except the torsion. This can be observed in Figure 2 which shows the variation of the mean overturning moments in the x and y directions with wind angle θ for the square tall building and the nine H-shaped buildings.

In this paper, wind load data are mainly presented as moment and torsion coefficients defined by equations such as:

$$C_{M_x} = \frac{M_x}{\frac{1}{2}\rho \overline{U}_H^{\,2} B H^2}, \quad C_{M_z} = \frac{M_z}{\frac{1}{2}\rho \overline{U}_H^{\,2} B^2 H} \qquad (1)$$

where $\overline{U}_H$ is the unobstructed mean wind speed at the building roof height. Mean moment coefficients are denoted by an over-bar and RMS coefficients by a prime.

Figure 3 shows the wind angle variations of the RMS moment coefficients of M_x and M_y. The effects of the size of recessed cavities on the moment coefficients are shown by grouping the data of buildings with the narrowest cavities (W/B = 0.25) the moderate-width cavities (W/B = 0.5), and the widest cavities (W/B = 0.75). At $\theta = 0$, wind incidence is normal to the building face with the recessed cavity and M_x is the across-wind moment . The results show that the square building experiences the most violent across-wind fluctuations at this normal incidence and the presence of recessed cavities on the windward and leeward faces leads to reduction of the levels of these fluctuations. The across-wind fluctuations are due to excitations connected with vortex shedding from the building. For a vortex-shedding circular cylinder, many studies show that the stagnation point at the front of the cylinder surface oscillates around the cylinder nose at the vortex shedding frequency (e.g., Sarpkaya and Schoaff 1979). It is speculated here there when a recessed cavity is present at the windward face, the mechanism of stagnation point movement is hindered and this may somewhat reduce the strength of vortex shedding. Very similar degrees of modification are observed on the nine H-shaped buildings. The width of the recessed cavities, as well as the depth, is found not to produce any noticeable differences to the modified behavior of M_x with θ of an H-shaped building from the square building.

When wind blows normally to the flat building face (θ = 90^o), the across-wind moment is M_y. The results in Figure 3 show that the presence of a narrow or moderate-width recessed cavity on the building side face only leads to very slight reduction in across-wind load fluctuations. For buildings with a wide cavity, more reduction in across-wind excitation is observed but with the exception of the moderate-depth cavity (W/B = 0.75, D/B = 0.5) which shows an increased magnitude of across-wind moment fluctuations. The H-shaped buildings with wide recessed cavities also experience higher levels of wind load fluctuations along the direction normal to the side faces with the cavities at all wind angles.

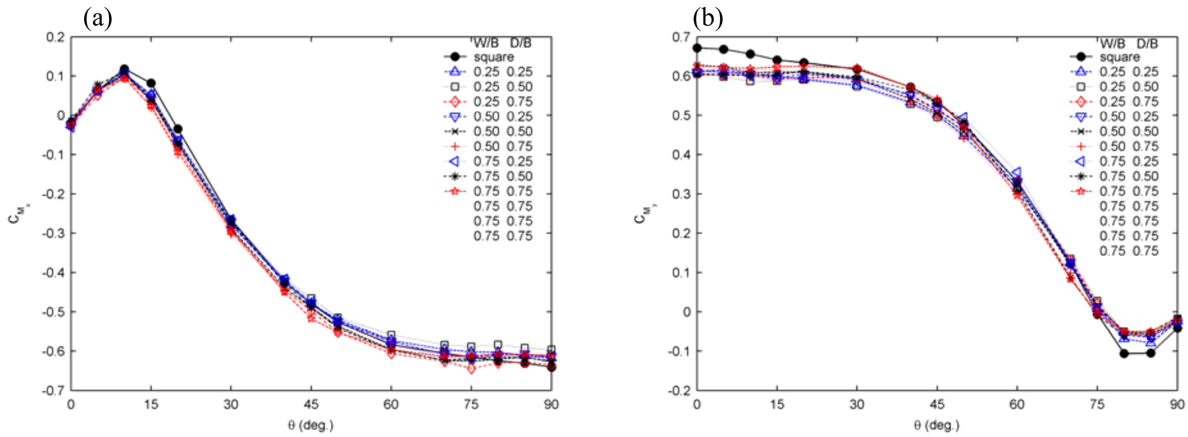

Figure 2: Mean overturning moment coefficients on square and H-shaped buildings.

Figure 4(a) shows the across-wind moment spectra of M_x at θ = 0^o for the three buildings with the widest recessed cavities and the control square building. It is evident that the power spectral level at the vortex shedding frequency of $nB/U \approx 0.1$ is significantly lowered in the presence of a wide cavity in the windward face. It is also evident that a deeper cavity leads to more reduction in across-wind excitation. At frequencies lower than the vortex excitation frequency, the H-shaped buildings experience higher levels of across-wind fluctuations. The values of RMS moment coefficients are C'_{Mx} = 0.162 for the square building, and {0.144, 0.139, 0.136} for the H-shaped buildings with the cavities at W/B = 0.75 and D/B = {0.125, 0.25, 0.375}, respectively. In the NatHaz database, a value of 0.1353 is quoted for a building model of very similar size at 4 inch × 4 inch × 24 inch in the open terrain (Zhou et al. 2003).

The along-wind moment spectra of M_y at θ = 0° are shown in Figure 4(b). The excitation is due to turbulence buffeting on the windward and leeward faces and the presence of a recessed cavity on these faces may be responsible for the increased spectral power at the high frequency end. In terms of the RMS moment coefficients and the overall spectral levels of the along-wind moment, the H-shaped buildings have similar values as the square building.

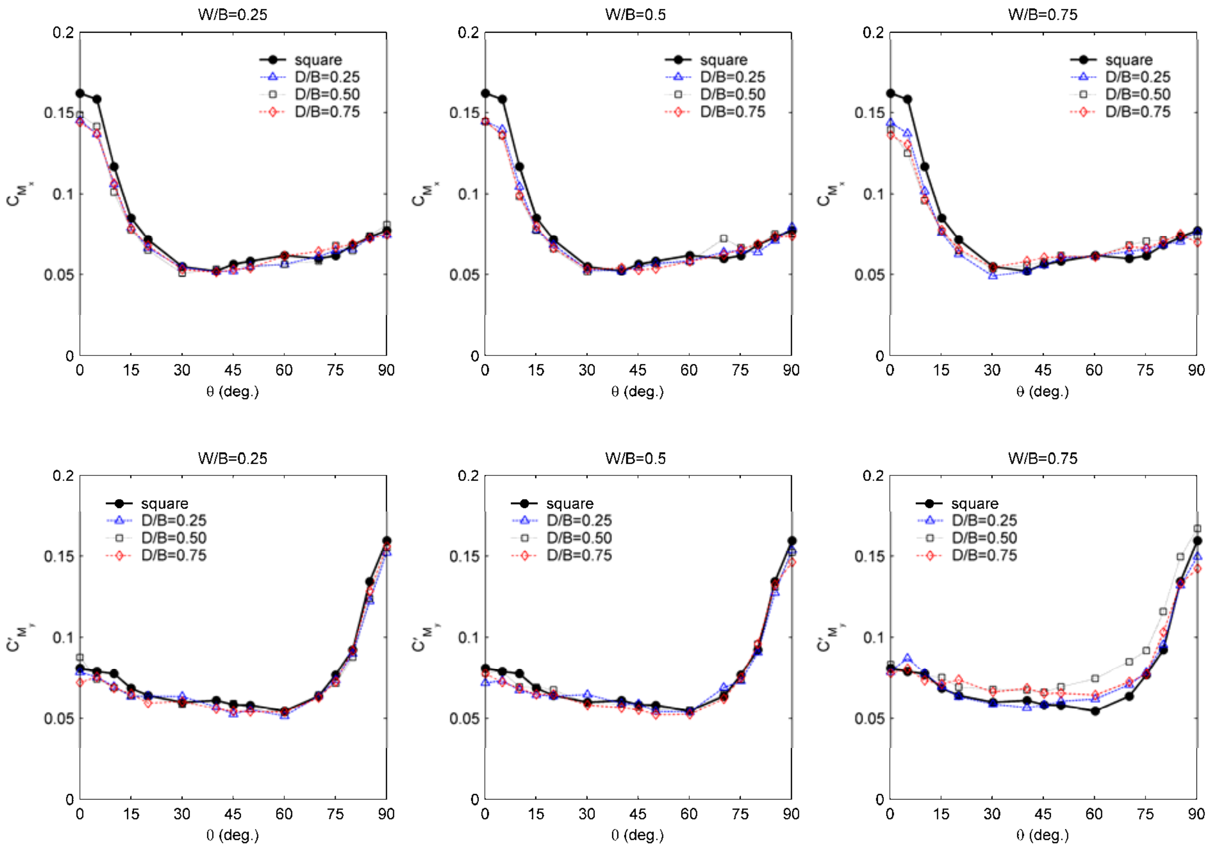

Figure 3: Effect of cavity sizes on RMS moment coefficients on square and H-shaped buildings.

At θ = 90°, wind is normal to the building face without a cavity and M_x becomes the along-wind spectra. Figure 3 shows that there are little differences in the RMS moment coefficients C'_{Mx} among all buildings at this incidence. The across-wind moment spectra of M_y are shown in Figure 5(b). Slightly higher spectral levels are found near the vortex excitation frequency on buildings with the widest cavities. At the lower frequency part, the H-shaped buildings have lower spectral power.

Figure 6 shows the moment spectra at θ = 45°. All the H-shaped buildings with the widest recessed cavity have increased power spectral levels higher at all frequencies than the square building. The increase is very significant at the vortex excitation frequency of $nB/U \approx$ 0.1.

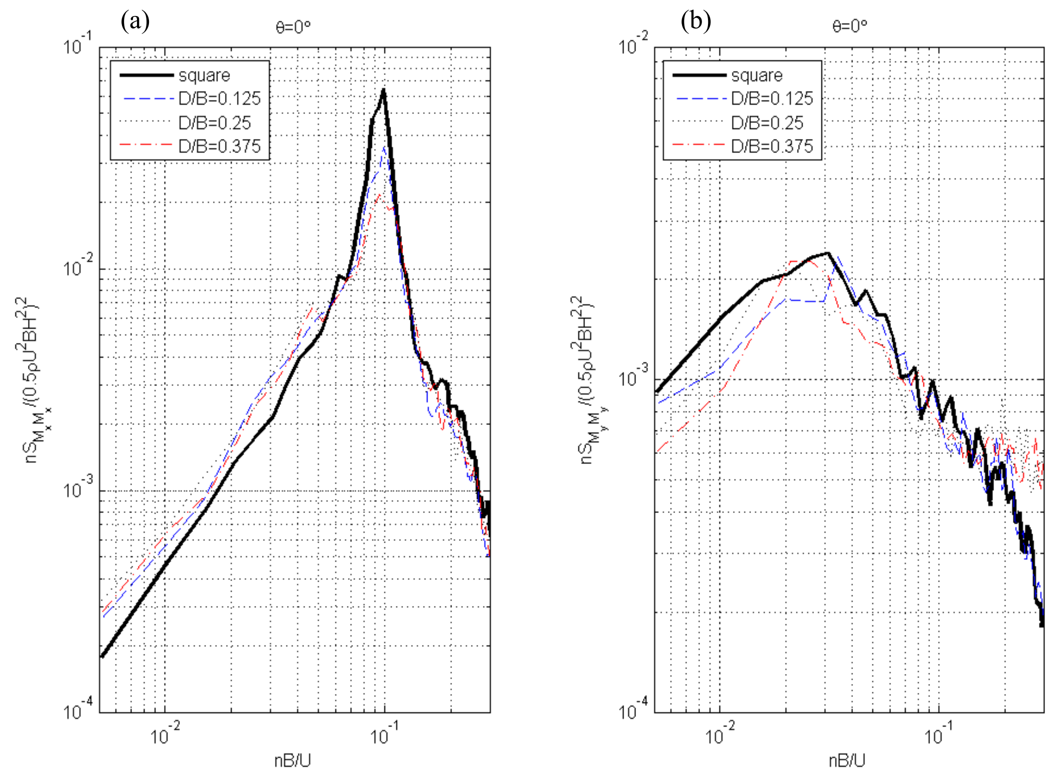

Figure 4: (a) Across-wind spectra M_x; and (b) along-wind spectra M_y at $\theta = 0^{o}$. Solid curve: square building; H-shaped buildings with cavities at W/B = 0.75.

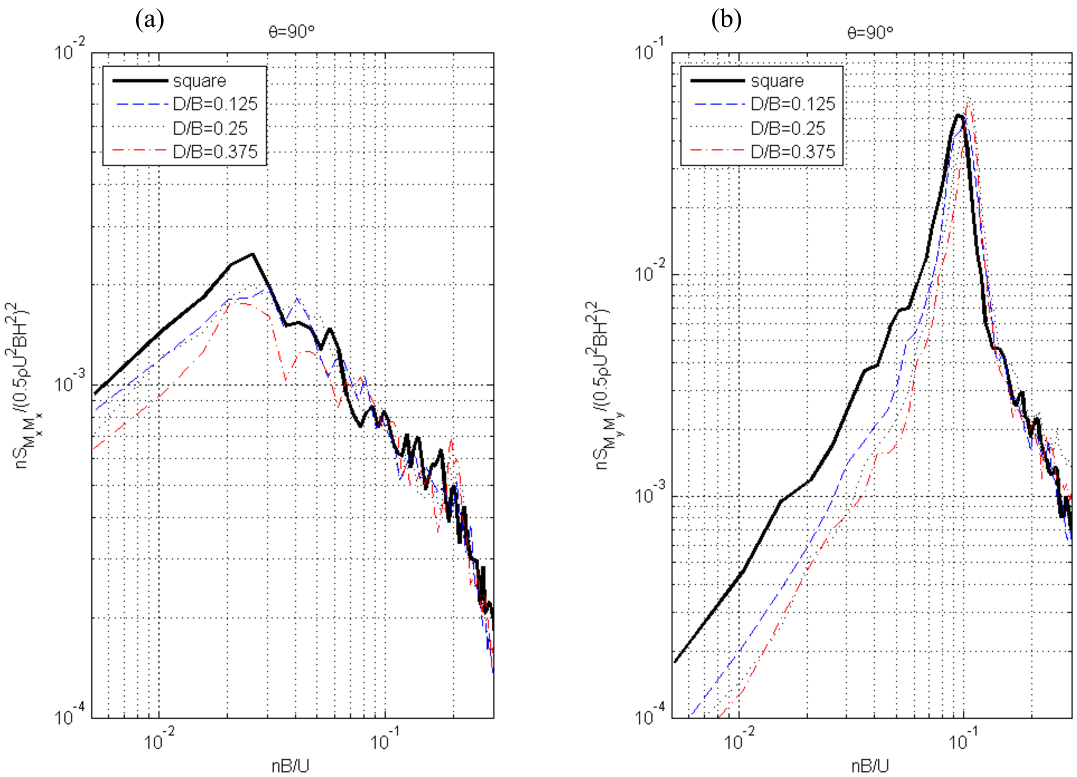

Figure 5: (a) Along-wind spectra M_x; and (b) across-wind spectra M_y at $\theta = 90^{o}$. Solid curve: square building; H-shaped buildings with cavities at W/B = 0.75.

The largest differences in dynamic wind loads between an H-shaped building and the control square building occur in wind torsion M_z. The variations of mean and RMS torsion coefficients with wind angles are shown in Figure 7 for all the nine H-shaped buildings. In general, the mean torsions have small magnitudes for all buildings and at all wind angles and there are uncertainties connected with an accurate measurement of these small mean torsions with the HFFB. Nevertheless, it is evident that the presence of recessed cavities leads to a non-zero mean torsion at θ = 45^{o}. The recessed cavities also result in increased levels of torsion fluctuations at all wind angles.

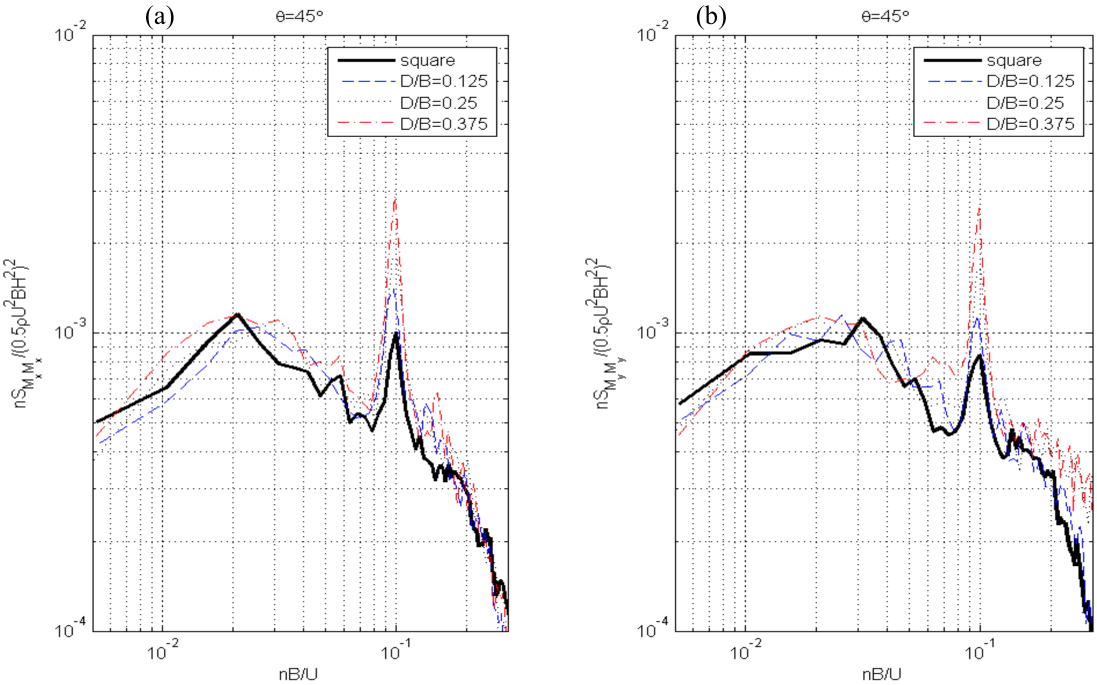

Figure 6: (a) Across-wind spectra M_x; and (b) along-wind spectra M_y at θ = 45^{o}. Solid curve: square building; H-shaped buildings with cavities at W/B = 0.75.

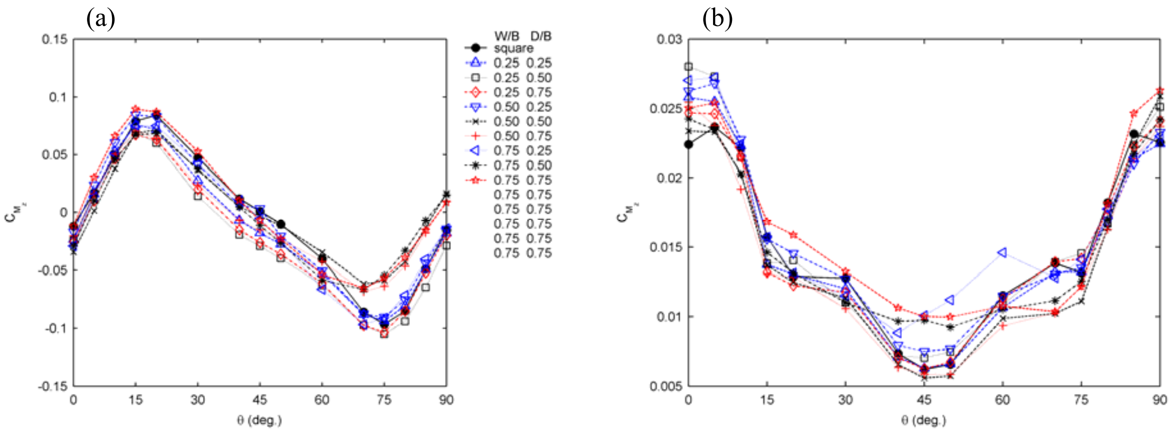

Figure 7: Variation of (a) mean; (b) RMS moment coefficient of M_z on square building (bold curve) and nine H-shaped buildings.

Examples of torsion spectra at normal and oblique wind incidences are shown in Figure 8 for H-shaped buildings with the widest the recessed cavities. Spectral peaks at vortex excitation frequency $nB/U \approx 0.1$ are observed in these spectra and large increase in this spectral levels occurs at $\theta = 45^o$ and 90^o.

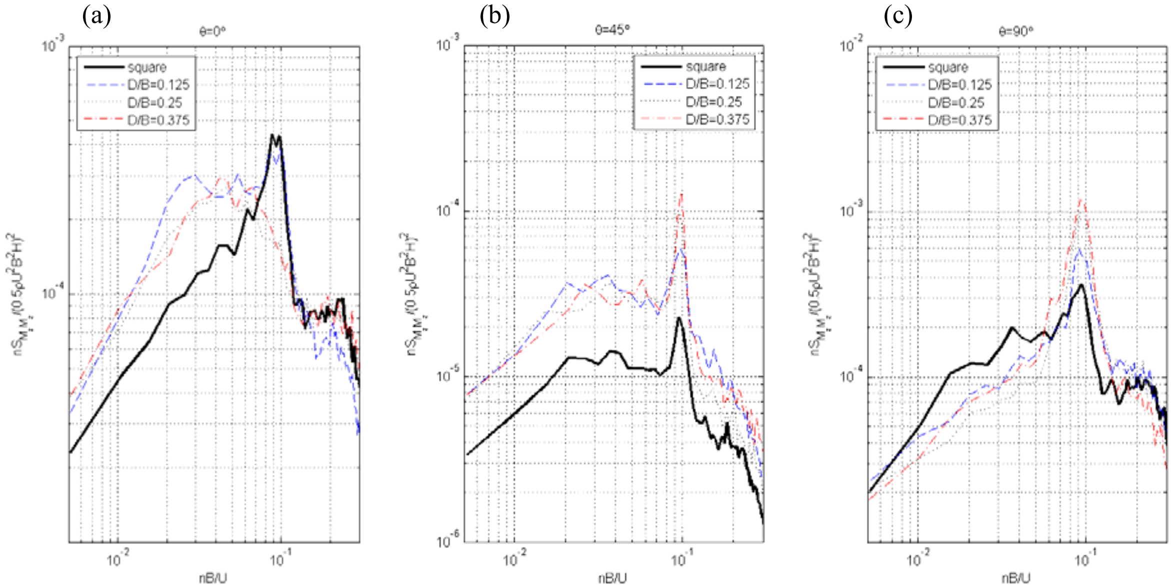

Figure 8: Torsion spectra at $\theta =$: (a) 0^o; (b) 45^o; (c) 90^o. Solid curve: square building; H-shaped buildings with cavities at $W/B = 0.75$.

Conclusions

This paper reports wind tunnel measurement data of dynamic wind loads on a number of H-shaped tall buildings with a high-frequency force balance. The building sections, all with the same square envelope, are formed by having two recessed cavities of varying sizes on opposite faces of the building. At most wind angles, presence of the cavities is found to cause little modifications to the variation of mean and fluctuating overturning moment coefficients with wind angles. For normal wind incidence on the building face with a cavity, fluctuations in the across-wind moment on an H-shaped building are found to have reduced magnitudes than the square building. The moment spectra show that the spectral level at the vortex excitation frequency is significantly reduced. The H-shaped buildings are found to experience noticeably higher fluctuating torsion than the square building. The results suggest than the width of the recessed cavities is critical in governing the wind load modifications.

Acknowledgement

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